Nitrogen use efficiency of cereals in arable organic farming

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Key words: crop rotation, spring barley, winter wheat, winter rye, nitrogen supply.

Abstract

The effect of nitrogen (N) supply and weeds on grain yield of spring barley, winter wheat and winter rye was investigated from 1997 to 2004 in an organic farming crop rotation experiment in Denmark on three soil types varying from coarse sand to sandy loam. Two experimental factors were included in the experiment in a factorial design: 1) catch crop (with and without), and 2) manure (with and without). The apparent recovery efficiency of N in grains (nitrogen use efficiency, NUE) from NH_4-N in applied manure varied from 29 to 38% in spring barley and from 23 to 44% in winter cereals. The NUE of above-ground N in catch crops sampled in November prior to the spring barley varied from 16 to 52% with the largest value on the coarse sandy soil and the smallest value on the sandy loam soil. The NUE of N accumulated in grass-clover cuttings varied from 14 to 39% with the lowest value on the coarse sandy soil, most likely due to high rates of N leaching. The NUE declined with increasing amounts of N accumulated in the grass-clover cuttings. This indicates that grain yields can be improved by removing the grass-clover cuttings and applying the N contained in the cuttings in spring to the cereal crops, possibly after fermentation in a biogas reactor.

Introduction

The productivity of arable crops in organic farming is restricted by the supply of nitrogen (N) (Olesen et al., 2007), and there is a need for sources of N in addition to manure to meet the N demand of cereals crops. Biological N fixation (BNF) is one of the primary sources of N in organic farming (Berry et al., 2002). The N supply through BNF will directly affect yields of legume crops. However, other crops will need to benefit from BNF through N recycled in manure or through crop residues returned to the soil. In systems with grass-clover for grazing or as green manures a major input of N from BNF is returned to the soil by incorporating the grass-clover pasture. Similar inputs are obtained from crop residues of grain legumes and from catch crops.

In the analysis of experiments with application of fertiliser N the apparent recovery efficiency of applied N is typically taken as a measure of the N use efficiency (NUE) (Cassman et al., 1998). NUE is usually calculated as the difference in N uptake between fertilised plots and an unfertilised control. However, it may also be calculated as the slope of a regression on crop N uptake (either N in total above-ground biomass

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or in grain yield) versus applied fertiliser N. In this paper we analyse the response of N input through green manures, crop residues, catch crops and animal manure on grain yield and N uptake in spring barley and winter cereals.

Materials and methods

A crop rotation experiment was initiated in 1996/97 at three sites in Denmark (Olesen et al., 2000). The sites represented different soil types (Jyndevad: coarse sand, Foulum: loamy sand, and Flakkebjerg: sandy loam) and climate regions in Denmark. In this paper we present results for cereals in a 4-course rotation with a pulse crop, spring barley, grass-clover and winter cereal. The pulse crop was a mixture of pea and barley in 1997 to 2000, lupin in 2001, a mixture of lupin and barley at Foulum and Flakkebjerg in 2002 to 2004, and a mixture of field bean, lupin and barley at Jyndevad in 2002 to 2004. The cereal and pulse crops were grown for grain harvest. The grass-clover was undersown in the spring barley in spring, and it was subsequently managed as a green manure crop with mulching of the cuttings. The grass-clover was followed by winter wheat, except for Jyndevad in 2001 to 2004 where it was followed by winter rye. All straw was left in the field. Weed harrowing was used where possible to control weeds in cereals and legumes. The experiment was irrigated at Jyndevad.

The experimental factors were 1) catch crop (with and without catch crop) and 2) manure (with and without animal manure applied as slurry). All crops in all rotations were represented every year in two replicates (blocks) in a two-factorial randomised design with plot sizes varying from 169 to 378 m^2. The plots receiving manure were supplied with anaerobically stored slurry at rates, where the NH_4-N amount corresponded to 40% of the N demand of the specific rotation based on a Danish national standard (Plantedirektoratet, 1997). In the catch crop treatment, a mixture of perennial ryegrass, chicory and various legume species were used.

Grain yields were measured at maturity using a combine harvester. Samples of total above-ground biomass were taken in each plot at growth stage 59 in spring barley and winter cereals. Each sample was separated into barley, grass-clover and weeds for assessing weed pressure. To determine the amount of crop residues returned to the soil, samples of total above-ground biomass were taken at growth stage 85, 1-2 weeks before yellow maturity in the pulse and cereal crops. Similar samples were taken about 1 November to measure the above-ground biomass of catch crops and weeds. Samples of total above-ground biomass in the grass-clover were taken at each cut. The dry matter content of grains and plant samples were determined after oven drying at 80 °C for 24 hours. Total N in the grains and plant samples were determined on finely milled samples from each plot by the Dumas method. Total N was not determined in the plant samples taken at GS 59. The amount of straw and other residues left on the soil after harvest of the previous crops was estimated from the samples of above-ground plant material taken at growth stage 85 by subtracting the grain dry matter yield.

The grain yield and grain N uptake in spring barley and winter cereals was related to inputs of N in various forms and to the weed pressure by linear regression. The following regression equation was used for spring barley:

$$Y = a_y + a_1 N_{man} + a_2 N_{res} + a_3 N_{Nov} + a_4 R_{wgc} \qquad (1)$$

and the following equation was used for winter cereals:

$$Y = b_y + b_1 N_{man} + b_2 N_{gc} + b_3 N_{gc}^{\ 2} + b_4 R_{wgc} \qquad (2)$$

where a_y *and* b_y are effects of year, and a_1-a_4 and b_1-b_4 are regression coefficients. N_{man} is ammoniacal N in the applied manure (kg N/ha), N_{res} is N in the above-ground residues from the previous crop (kg N/ha), N_{Nov} is N in the above-ground plant parts on 1 November (kg N/ha) prior to spring barley, N_{gc} is accumulated N in the above-ground biomass of the previous grass-clover (kg N/ha), and R_{wgc} is weed and grass-clover biomass as per cent of total above-ground dry weight at growth stage 59.

Results

There were generally consistent yield benefits from N in manure with average grain yield increases of appox. 20 kg DM/ha per kg NH_4-N in manure with slightly lower values at Flakkebjerg for both spring barley and winter wheat (Tables 1 and 2). The apparent N recovery efficiency (NUE) taken as the slope of N uptake in grain to the N input in manure was highest at Foulum and similar at Jyndevad and Flakkebjerg for both crops (see coefficients of N_{man} under grain N uptake, which is the recovery efficiency (NUE)).

The were insignificant effects of N in above-ground residues of pulses on grain yield and N uptake in spring barley (Table 1). Grain yields of winter wheat responded strongly to accumulated N in the mulched grass-clover cuttings, especially at Flakkebjerg (Table 2). However, this response was non-linear as seen by the negative coefficient for $N_{gc}^{\ 2}$, which results in a saturation response. This means that the NUE is reduced with increasing N input, resulting in NUE values of only 9, 14 and 16% at Jyndevad, Foulum and Flakkebjerg, respectively, for an N input in grass-clover of 300 kg N/ha.

The grain yield response of spring barley to N in the catch crop samples in November showed large site differences with considerably higher responses at Jyndevad compared with Flakkebjerg (Table 1). The associated NUE showed similar site differences, but the NUE for spring barley from N in catch crop was in all cases higher than the NUE for winter cereals from N in grass-clover (compare Tables 1 and 2).

There were negative effects of weeds and undersown catch crop or grass-clover on cereal yields. The effects of weeds on NUE were considerably more pronounced for winter cereals compared with spring barley (compare Tables 1 and 2).

Discussion

The results demonstrate that the yield benefits and the NUE from manure application are considerably more consistent across sites than the effects of various types of N in green manure or crop residues. The lower yield benefits from manure application at Flakkebjerg compared with the other sites can probably be explained by a higher ammonia volatilisation due to reduced infiltration of the slurry on this soil type.

A large part of the site differences in grain yield response to inputs of N in grass-clover and catch crops can probably be explained by differences in N leaching during winter. The combination of a sandy soil and relatively high rainfall gives a high risk of N leaching at Jyndevad compared with the other sites. The soil at Flakkebjerg has the highest N retention and the lowest rainfall. The benefits of using catch crops in terms of retaining N in the system are therefore highest at Jyndevad and lowest at

Flakkebjerg. The risk of loosing N from the autumn-ploughed grass-clover is similarly highest at Jyndevad and lowest at Flakkebjerg, resulting in large differences in the NUE of N in grass-clover.

The low NUE of N in grass-clover at Jyndevad and the non-linear response of yield to increasing N input in grass-clover suggests that the N supply to the cereal crops may be improved by harvesting the grass-clover cuttings and applying it to the crops in spring in the form of manure, possibly after anaerobic digestion in a biogas reactor.

Table 1. Regression coefficients from regression of grain yield and N uptake of spring barley, 1998-2004, on ammoniacal N in manure (N_{man}), N in the above-ground residues of the previous crop (N_{res}), N in above-ground weeds and catch crop in November prior to spring barley (N_{Nov}) and weed and undersown grass-clover as percent of total above-ground dry weight at growth stage 59 in spring barley (R_{wgc}).

Variable	Location	N_{man}	N_{res}	N_{Nov}	R_{wgc}
Grain DM yield	Jyndevad	23.0	2.3	32.1	-29
(kg DM/ha/yr)	Foulum	20.9	-0.1	15.4	-44
	Flakkebjerg	16.9	3.3	9.6	-23
Grain N uptake	Jyndevad	0.29	0.04	0.52	-0.49
(kg N/ha/yr)	Foulum	0.38	0.03	0.33	0.67
(NUE)	Flakkebjerg	0.30	0.05	0.16	0.07

Table 2. Regression coefficients from regression of grain yield and N uptake of winter cereals, 1998-2004, on ammoniacal N in manure (N_{man}), N in above-ground biomass at time of cutting in the previous grass-clover (N_{gc}) and weed and undersown grass-clover as percent of total above-ground dry weight at growth stage 59 in winter cereals (R_{wgc}).

Variable	Location	N_{man}	N_{gc}	N_{gc}^2	R_{wgc}
Grain DM yield	Jyndevad	17.2	4.4	-0.004	-32
(kg DM/ha/yr)	Foulum	22.4	9.9	-0.011	-18
	Flakkebjerg	12.0	14.6	-0.016	-92
Grain N uptake	Jyndevad	0.23	0.09	-0.00006	-0.6
(kg N/ha/yr)	Foulum	0.44	0.21	-0.00022	-0.5
(NUE)	Flakkebjerg	0.23	0.27	-0.00030	-1.7

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